Teacher Guide: Penumbra Effect

Learning Objectives

Students will …

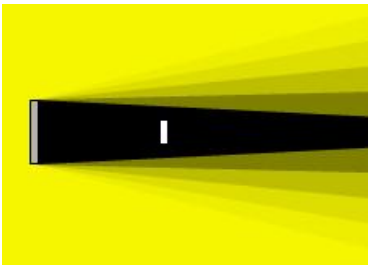
- Observe shadows created by single point sources and multiple point sources of light.
- Identify the umbra and penumbra.
- Identify from where each part of the penumbra receives its light.
- Describe how the following factors affect the shape of the umbra and penumbra: light spacing, width of the object, and distance between the lights and the object.

Vocabulary

eclipse, penumbra, point source, umbra

Lesson Overview

On a sunny day, shadows have sharp edges. On cloudy days or indoors, shadows usually have graded, "fuzzy" edges. If a light source is only partially blocked, the resulting shadow will have a wide edge called the *penumbra*. The *Penumbra Effect* Gizmo™ allows students to determine how the penumbra forms and explore the factors that influence the size and shape of the penumbra.



The Student Exploration sheet contains one activity. In this activity, students model the formation of a penumbra with multiple point sources of light. Students then investigate how the light spacing, object size, and distance between light sources and object affect the shape of the umbra and penumbra.

Suggested Lesson Sequence

1. **Pre-Gizmo activity: Fuzzy shadows** (5 – 10 minutes)
   Darken your room, turn on an overhead projector, and focus the light on a screen. Hold a pencil close to the screen, and then move the pencil away from the screen. Ask students to describe how the shadow of the pencil changes as you move it away from the screen. If you like, experiment with other objects as well.

   Ask students why the shadows become "fuzzy" as the objects move closer to the projector. What would students see if they were standing in the object's shadow as it was moved farther away?

2. **Prior to using the Gizmo** (10 – 15 minutes)
   Before students are at the computers, pass out the Student Exploration sheets and ask students to complete the Prior Knowledge Questions. (These questions ask students about shadows while they stand in front of a lamp. If you are able to, allow students to stand up and do the activity in the classroom.) Discuss student answers as a class. Afterwards, if possible, use a projector to introduce the Gizmo and to demonstrate its basic operations, such as how to take Gizmo snapshots.

3. **Gizmo activities** (15 – 20 minutes per activity)
   Assign students to computers. Students can work individually or in small groups. Have students work through the activities in the Student Exploration, using the Gizmo. Alternatively, you can use a projector and do the Exploration as a teacher-led activity.

4. **Discussion questions** (15 – 20 minutes)
   As students are working or just after they are done, discuss the following questions:
   - What is the relationship between the number of light sources and the number of gradations observed in the penumbra?
   - How does the length of the umbra change as the distance between the object and the light source increases or decreases?
   - Jupiter is larger than Earth and farther from the Sun. How would the umbra of Jupiter compare to the umbra of Earth? [Jupiter's umbra will be longer and wider than Earth's.]
   - In the Gizmo, you can see the penumbra created by multiple point sources. What would the penumbra look like if the row of point sources was created by a single, broad source of light such as the Sun? [The penumbra would show a continuous gradation from light to dark.]

5. **Follow-up activity: Making a penumbra** (20 – 30 minutes)
   Set up a real-world version of the Gizmo using overhead projectors as light sources. (The projectors should be close together and about 5–10 meters from the screen.) Place a book on a table about 1 meter in front of the screen to create shadows. First, focus the light from two projectors on the book. The shadow on the screen should show two distinctive parts: a central dark umbra surrounded by a lighter penumbra. Ask students to identify these parts of the shadow.

   If possible, increase the number of projectors shining on the book to three or four. Give each projector a number and ask students to identify which projectors are visible (and are blocked) from each portion of the shadow. These can be checked by turning each projector off in turn.

   Finally, experiment by changing the spacing of projectors, the distance between the object and the screen, the distance between the object and the projectors, and the size of the object.

Scientific Background

When light is emitted from a single point, or *point source*, it radiates into space in all directions. If an object is placed in the path of the light, the resulting shadow will be completely dark as 100% of the light is blocked within the shadow. This type of shadow is called an *umbra*.

If light is emitted from more than one source (or the light source is not a single point), the umbra will be surrounded by an area where only part of the light is blocked. This region is the penumbra. An observer standing in the penumbra will see part of the light source, but not all of it. If the light comes from a series of point sources, the penumbra will show stepped gradations that are darkest next to the umbra. If the light comes from a single, wide source, the penumbra will grade continuously from light to dark.

Several factors affect the shape of the umbra and penumbra. The farther the object is from the light source, the more parallel the light rays are when they hit the object. This will have the effect of narrowing the penumbra and lengthening the umbra. This is illustrated in the diagrams below:

Increasing the spacing of the light sources (or the width of a single light source) will make the penumbra wider and the umbra shorter. Making the object wider will have the effect of lengthening the umbra *and* widening the penumbra. The size of the observed penumbra is also affected by how close the object is to a screen, wall, or sheet of paper that the shadow is projected onto. The closer the object is to its shadow, the smaller the observed penumbra will be. This explains why, for example, the shadow of a pencil is much sharper when the pencil is held close to a screen.

Astronomy Connection: Eclipses

While almost any shadow has a penumbra, the penumbra effect is most often discussed in the context of eclipses. Both the Earth and Moon have shadows that include an umbra and a penumbra. A *solar eclipse* occurs when the shadow of the Moon passes across Earth's surface. A *lunar eclipse* occurs when Earth's shadow falls across the surface of the Moon.

During a solar eclipse, an observer in the Moon's penumbra will experience a *partial solar eclipse*, in which the observer sees the Moon covering a part of the Sun. An observer in the Moon's umbra will experience a *total solar eclipse*, in which the Sun is completely covered by the Moon.

Similarly, a lunar eclipse occurs in two phases. First, Earth's penumbra passes across the Moon's surface, resulting in a *penumbral eclipse*. Penumbral eclipses result in a slight dimming of the Moon but usually are not very noticeable. Next, Earth's umbra passes across the Moon's surface. If the Moon is completely covered by Earth's umbra, the result is a *total lunar eclipse*. If the Moon is only partly covered by Earth's umbra, it is a *partial lunar eclipse*.

Selected Web Resources

Umbra & penumbra: http://www.learner.org/workshops/sheddinglight/highlights/highlights1.html, http://en.wikipedia.org/wiki/Umbra
Penumbra activity: http://www.learner.org/teacherslab/science/light/lawslight/player/index.html
Solar eclipses: http://www.mreclipse.com/Special/SEprimer.html
Lunar eclipses: http://www.mreclipse.com/Special/LEprimer.html

Related Gizmos:
Eclipse: http://www.explorelearning.com/gizmo/id?644
2D Eclipse: http://www.explorelearning.com/gizmo/id?556
3D Eclipse: http://www.explorelearning.com/gizmo/id?462